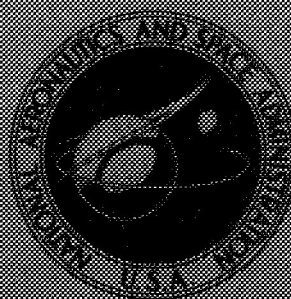NASA TECHNICAL
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MOTOR-STARTING CHARACTERISTICS
OF A MODIFIED LUNDELL ALTERNATOR

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16. Abstract

A modified Lundell, or Rice, alternator designed for use in a single-shaft Brayton-cycle space-power system was started as an induction motor. Armature current, rotational speed, and field voltage were measured. Torque was computed from its relation to measured acceleration and moment of inertia.

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LUNDELL ALTERNATOR

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SUMMARY

A modified Lundell, or Rice, alternator designed for use in a single-shaft Brayton-cycle 1200-hertz space-power system was started as an induction motor. Armature current, rotational speed, and field voltage were measured. Torque was computed from its relation to measured acceleration and moment of inertia. For the ratio of rated voltage to frequency of 0.1 volt per hertz, starting torque was approximately 1.7 per-unit at both 400 and 800 hertz, and 1.5 per-unit at 1200 hertz. Armature currents during startup were quite high, being a maximum of 4.6 per-unit at rated voltage and frequency.

INTRODUCTION

For a single-shaft Brayton-cycle space-power system (ref. 1), one method of startup being considered is motoring of the solid-rotor alternator. The motor-starting characteristics of the alternator are required in order to determine startup procedures and power-supply requirements.

Data on the motor-starting characteristics of solid-rotor machines are limited. In a previous investigation (ref. 2), the motor-starting characteristics of two homopolar inductor alternators were experimentally determined. Analytical and experimental studies of induction motors with solid cylindrical rotors have also been performed (refs. 3 to 6). In reference 7, Concordia analyzes the motor-starting characteristics of synchronous machines.

In the Brayton-cycle system in reference 1, the alternator is a brushless stationary-coil solid-rotor modified Lundell, or Rice, machine. Since its motor-starting characteristics could not be predicted analytically, they were determined from an experimental program. In reference 8, some motor-starting characteristics of the Brayton rotating unit (turbine, alternator and compressor) are presented. These data are primarily for

an applied frequency of 400 hertz. Only starting torques and currents are given for frequencies other than 400 hertz. In this report, test results are presented for the alternator alone at various frequencies and voltages and include data on torque, armature current and induced field voltage over the entire speed range from zero to synchronous.

These data will be useful for a study of a motor start for the Brayton-cycle system. Acceleration of the Brayton rotating unit (BRU) results from the net torque of the alternator, compressor, turbine, bearings, and windage. Thus, to accurately predict motor-starting characteristics, information is needed for all these components. This report gives the pertinent information on the alternator. From the torque characteristics, system starting times can be estimated, and the optimum voltage and frequency can be determined. From the expected armature current the size of the batteries and inverter needed for motor starting can be determined.

APPARATUS

Description of Alternator

The modified Lundell, or Rice, alternator used in this investigation is described in references 9 and 10. For convenience, some of the more important design parameters are listed in the following table.

Rating, kW. 10. 7
Power factor. 0. 75
Phases. 3
Voltage, V. 120/208
Current, A. 39. 7
Speed, rpm 36 000
Rotor outside diameter, in. (cm). 3. 26 (8. 28)
Rotor pole pitch 0. 667
Rotor material. . . . . SAE 4340
Rotor diameter at auxiliary air gap, in. (cm) 2. 19 (5. 56)
Stator inside diameter, in. (cm) 3. 3 (8. 38)
Stack length, in. (cm). 1. 65 (4. 19)
Lamination material. . . . . AL 4750
Lamination thickness, in. (cm). 0. 004 (0. 0102)
Slots 36
Conductors per slot 18
Turns per coil. 9
Effective series turns. 22. 44
Strands per turn. 5
Parallel circuits. 4
Coil pitch 2/3

Figure 1 is a photograph of the complete assembled experimental alternator. A photograph of the rotor showing the magnetic and nonmagnetic sections is presented in figure 2. This alternator has two windings per field coil, which is of importance in reporting the test results.

Power Supply

A variable-frequency motor-generator set was used as a power supply in the motor starting tests. This unit has a frequency range of 200 to 2000 hertz and has a maximum power output capability of 200 kilowatts.

Instrumentation

The instrumentation for these tests consisted of an oscillograph having a frequency range of 0 to 5000 hertz, depending on the galvanometer used. The linearity was ±2 percent of the reading for deflections of 4 inches (10 cm) or less. Speed was measured with a capacitance probe in conjunction with a six-toothed gear; a signal conditioner produced a dc voltage proportional to rotor speed.

Procedure

The alternator by itself, without any other equipment coupled to the shaft, was accelerated from zero to synchronous speed at test frequencies of 400, 800, and 1200 hertz. For each frequency, data were obtained for voltage-to-frequency ratios of 0.1, 0.075, and 0.05 volt per hertz. A ratio of 0.1 volt per hertz corresponds to rated voltage at that particular frequency (i.e., 120 V, line-to-neutral, at 1200 Hz).

Armature current, line voltage, field voltage, and speed were recorded as functions of time. Torque was computed from its relation to moment of inertia and angular acceleration. Any torques from bearing friction or rotor windage loss were neglected. Since the line voltage varied during the test, torque, current, and field voltage were corrected to the desired voltage by means of conventional induction-motor equations.

For the tests, the two fields of the alternator were connected in series and shunted by a 50-ohm resistor.

RESULTS AND DISCUSSION

Torque

The torque of an electromechanical machine is proportional to the vector product of the gap flux density and the rotor magnetomotive force (ref. 11). For a solid-rotor machine such as the Lundell alternator, both the rotor magnetomotive force and the flux are significantly affected by the eddy currents induced in the solid-iron rotor. To a lesser degree, motor-starting performance is modified by currents induced in the stationary field coil.

Figure 3 shows the torque-speed characteristics of the machine as a function of both frequency and voltage. Torque is presented in the per-unit system. One per-unit torque is defined as the torque of the machine as an alternator at rated speed and power, which for this case is 2.09 pound-feet (2.83 N-m).

The torque characteristics resemble those that would be obtained from a conventional induction motor with a high-resistance rotor. This is as expected because the induced rotor currents flow in a high-resistivity magnetic material. For a voltage-to-frequency ratio of 0.1 volt per hertz, starting torque is approximately 1.7 per-unit at both 400 and 800 hertz and 1.5 per-unit at 1200 hertz.

Armature Current

Figure 4 gives the armature-current characteristics of the machine for the various test conditions. For a voltage-to-frequency ratio of 0.1 volt per hertz, the maximum current is 3.1 per-unit at 400 hertz, 4.0 per-unit at 800 hertz, and 4.6 per-unit at 1200 hertz. These data show that the current requirements of the power supply will be high if the Lundell alternator is used as an induction motor for system startup. These currents should not cause any damage to the alternator since during startup they would be present for only a relatively short time of a few seconds.

Field Voltage

The field voltage characteristics of the machine were determined with the two field coils wired in series and shunted by a 50-ohm resistor to limit the induced voltage (fig. 5). The maximum voltage obtained was about 12.5 volts which is low enough not to cause any damage to the field insulation. The voltage has an ascending characteristic with increasing speed with a dip at about 50-percent speed. At about 95-percent speed, the field voltage begins to decrease rapidly and becomes zero at 100-percent speed. These results are similar to those observed in reference 2.

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System Requirements

Figure 6 shows starting torque plotted against starting current for the various test frequencies. From these curves, it can be seen that the highest starting torques and lowest starting currents are obtained at a frequency of 400 hertz. Thus it would be desirable to motor start the BRU using 400 hertz since this frequency would impose the least severe current requirements on the inverter power supply for a given starting torque.

When the Brayton-cycle system is motor started, it is expected that the system will become self-sustaining at 12 000 rpm. A frequency of 400 hertz could therefore be used to accelerate the alternator to this speed. A minimum voltage of about 30 volts would probably be needed to develop sufficient torque during acceleration to get to synchronous speed.

SUMMARY OF RESULTS

The motor-starting characteristics of a solid-rotor modified-Lundell alternator were experimentally determined. This alternator is designed for use in a single-shaft Brayton-cycle space-power system.

For a voltage-to-frequency ratio of 0.1 volt per hertz, starting torque is approximately 1.7 per-unit at 400 and 800 hertz and 1.5 per-unit at 1200 hertz. Starting currents were quite high, being a maximum of 3.1 per-unit at 400 hertz, 4.0 per-unit at 800 hertz, and 4.6 per-unit at 1200 hertz.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 6, 1970,
120-27.

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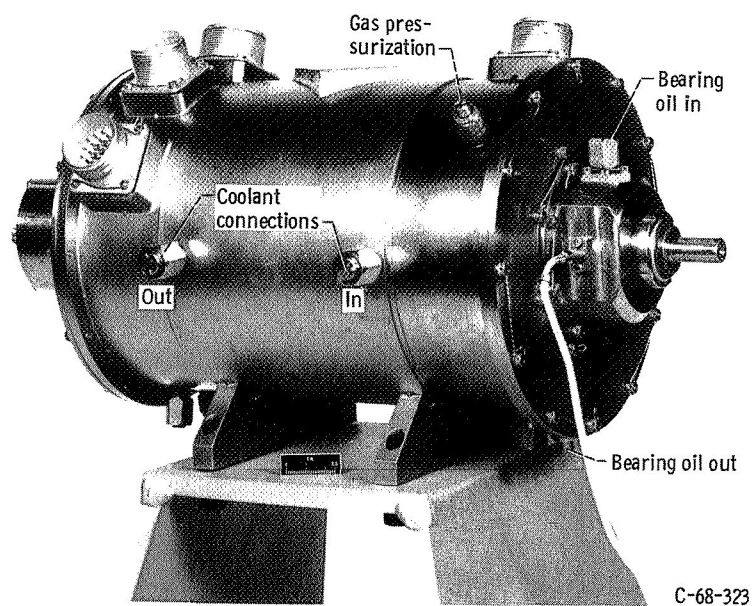
Figure 1. - Experimental alternator.
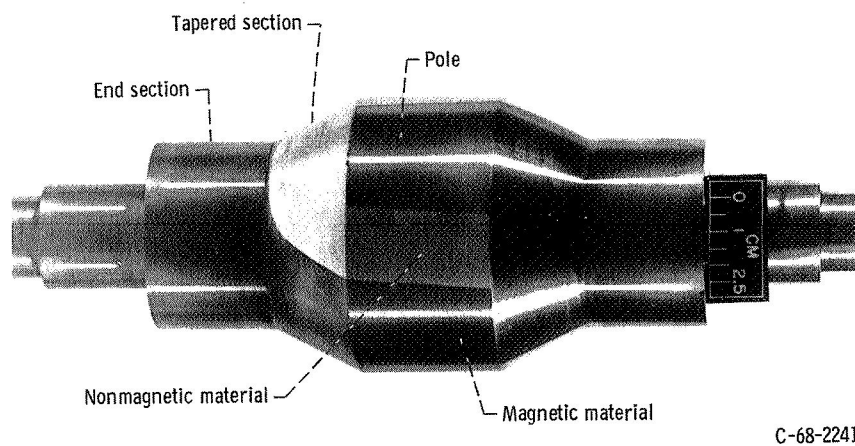
Figure 2. - Alternator rotor.
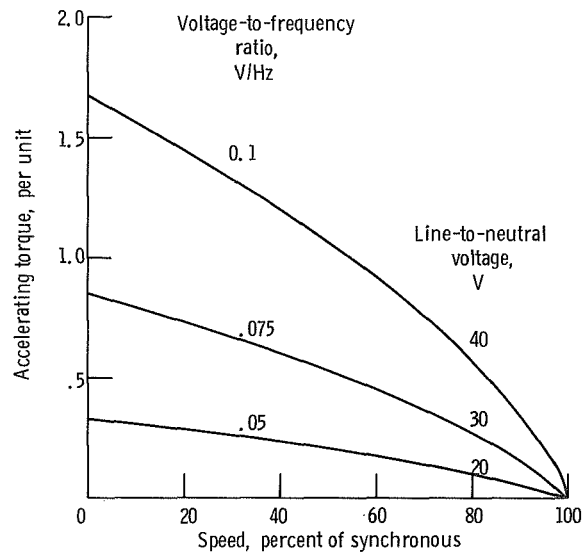
(a) Applied frequency, 400 hertz; synchronous speed, 12 000 rpm.
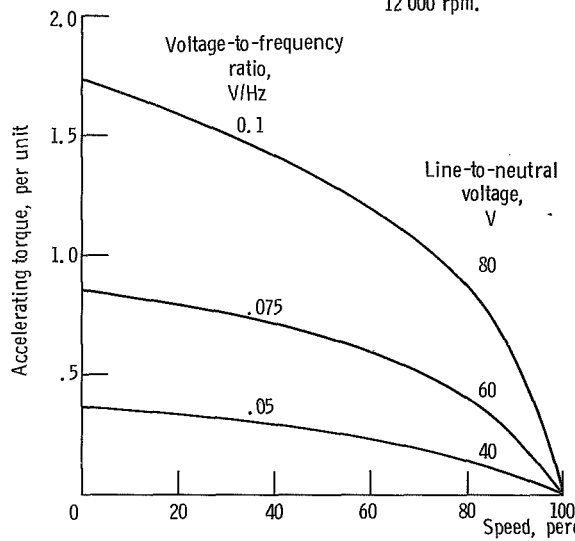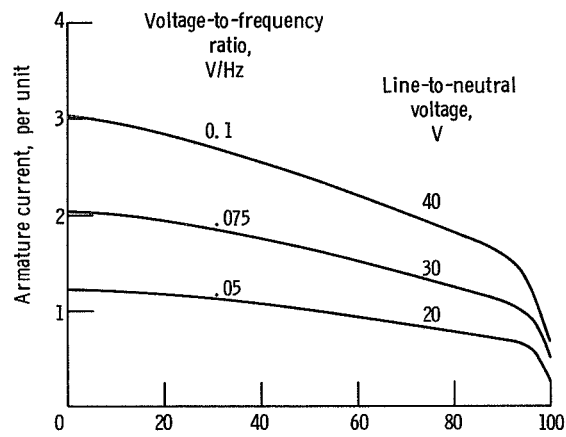
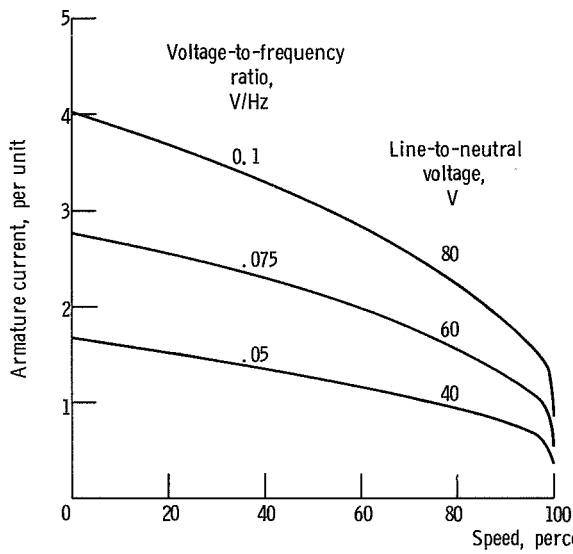(b) Applied frequency, 800 hertz; synchronous speed, 24 000 rpm.
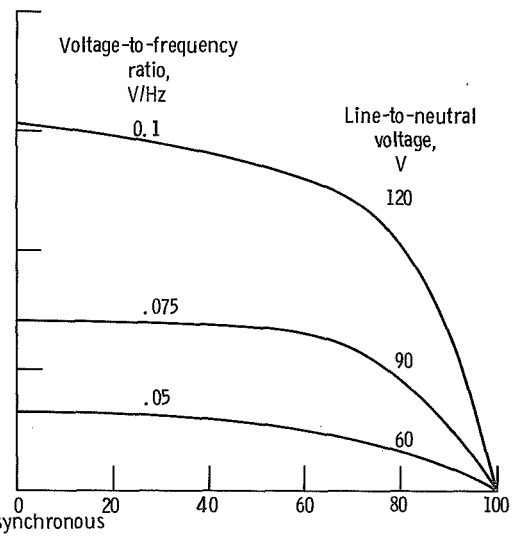
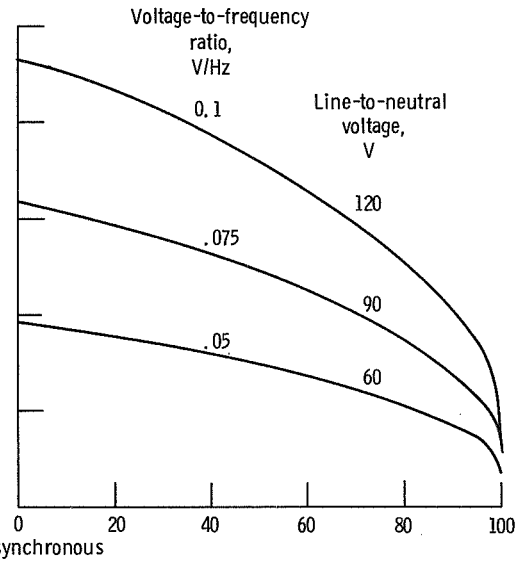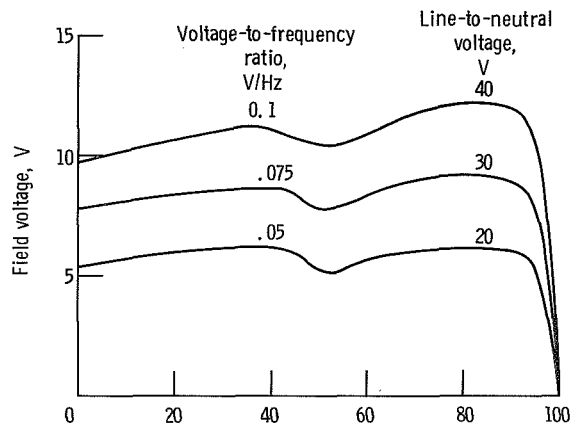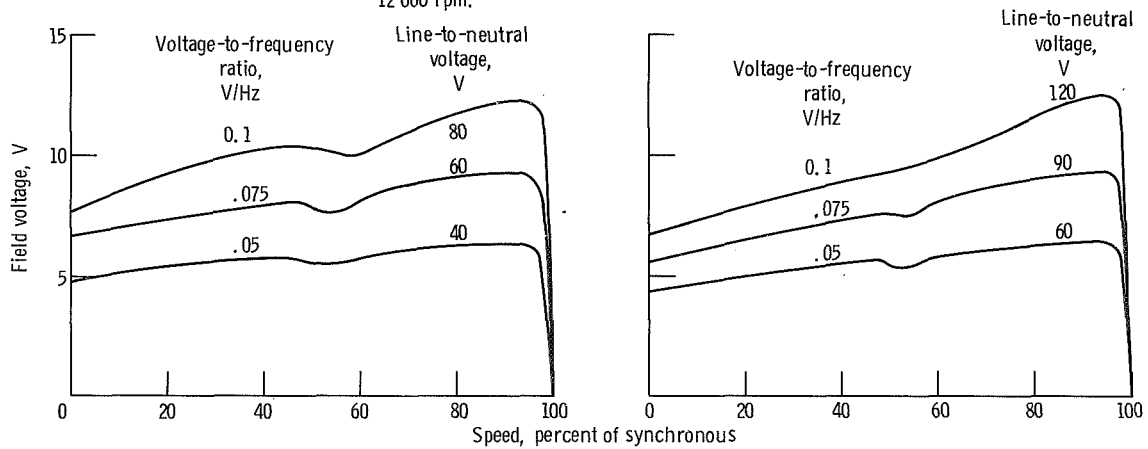(c) Applied frequency, 1200 hertz; synchronous speed, 36 000 rpm.

Figure 3. - No-load motor-torque characteristics of 1200-hertz Lundell alternator. One per-unit torque, 2.09 pound-feet (2.83 N-m).

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(a) Applied frequency, 400 hertz; synchronous speed, 12 000 rpm.

(b) Applied frequency, 800 hertz; synchronous speed, 24 000 rpm.

(c) Applied frequency, 1200 hertz; synchronous speed, 36 000 rpm.

Figure 4. – No-load motor starting armature current characteristics of 1200-hertz Lundell alternator. One per-unit current, 39.7 amperes.

(a) Applied frequency, 400 hertz; synchronous speed, 12 000 rpm.

(b) Applied frequency, 800 hertz; synchronous speed, 24 000 rpm.

(c) Applied frequency, 1200 hertz; synchronous speed, 36 000 rpm.

Figure 5. - No-load motor starting field voltage characteristics of 1200-hertz Lundell alternator.
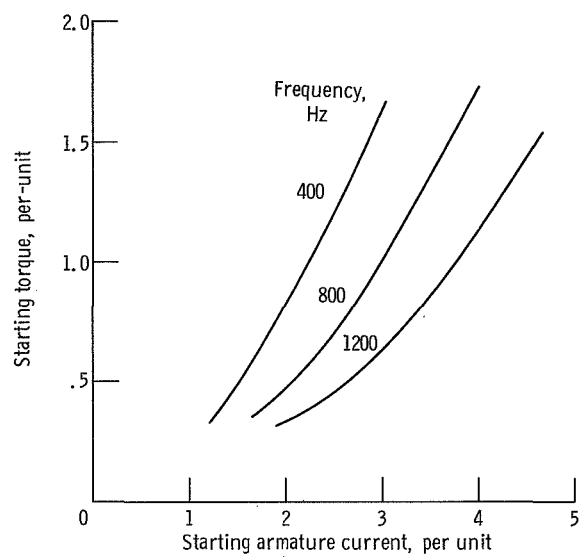
10

Figure 6. - No-load starting torque as function of arma-
ture current for 1200-hertz Lundell alternator. One
per-unit torque, 2.09 pound-feet (2.83 N-m); one per-
unit current, 39.7 amperes.

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